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General Technical
Report RM-160

# Recent Historical and Projected Regional Trends of Trout in the Southeastern United States

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The recent history of trout in the Southeastern United States is described. A statistical relationship established between current trout density and land use and forest cover in watersheds is the core of a projection tool that evaluates impacts of expected future and alternative timber management on trout for regional and national assessments.

**Keywords:** Multiresource analysis, regional model, Southeast, statistical model, trout, trout habitat

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# Recent Historical and Projected Regional Trends of Trout in the Southeastern United States

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**Abstract**

This research was motivated by the need for regional assessments of fish resources in a multiple resource context. The current and historical status of brook, brown, and rainbow trout in the Southeastern United States was reviewed. To analyze effects of projected land use changes and timber management alternatives on trout, a fish model was developed within a multiple resource framework that links fish, forage, wildlife, and water to land use and timber. Discriminant function analysis was used to determine the relationship between trout density classes and runoff, land use, and forest cover in coldwater watersheds of the region. Projected land base changes for a baseline and several alternative scenarios were applied to the trout model to assess impacts of various economic assumptions and timber management decisions. Over the 50-year projection period, trout density declined in response to increased human land use acreages and decreased old-age hardwood acreages for all scenarios. The feasibility of a regional approach to analysis of trout habitat relationships was demonstrated. This research points to the need for management of trout on a regional scale, in a multiple resource context, as well as at the stream level.

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## Contents

# Recent Historical and Projected Regional Trends of Trout in the Southeastern United States

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## INTRODUCTION

The Forest and Rangeland Renewable Resource Planning Act of 1974 (RPA)[2] as amended by the National Forest Management Act of 1976 (NFMA)[3] requires that the USDA Forest Service make decadal national assessments of renewable natural resources. Wildlife and fish are specific resource categories to be evaluated in the RPA assessment.

The first assessment, in 1975 (USDA FS 1977), prepared shortly after enactment of the RPA and NFMA, was organized according to fish and wildlife uses, including a brief section on fishing. Fishing was identified as one of the most popular and fastest growing outdoor recreation activities, and management opportunities for improving fish supply were limited.

In the 1979 assessment document (USDA FS 1981), supplies of and demands for selected fish species were compared in a largely descriptive manner. The emphasis was on the current situation (mid-1970's), with a few references to historical supply or demand. Participation in major fishing activities (i.e., saltwater and freshwater fishing by region) was projected from 1977 to 2030. Freshwater fishing participation in the Southeast was projected to increase 20% by 1990 and 106% by 2030 over 1977 levels, compared to increases of 18% and 90%, respectively, for the nation as a whole. Increasing importance of stocking and aquaculture to meet the demand for fish was noted. Implications of not meeting demands for both commercial and recreational users, problems in improving the status of fish, and opportunities to maintain and enhance the fish resource were discussed. In the final section, the authors noted that, except for a few important commercial and recreational species, little quantitative supply or demand information was available (USDA FS 1981:151). Fish population estimates were particularly rare. Two major criticisms of the 1979 assessment were (1) lack of analytical capability, and (2) resources were addressed independently rather than with multiple resource analyses (Schweitzer et al. 1981).

Since that assessment, technical specifications for the next national assessment of wildlife and fish, in 1989, have been described. For purposes of organizing the 1989 assessment, Hoekstra and Hof (1985) identified four major attributes of wildlife and fish resources—population, habitat, harvest, and users—and interpreted the national assessment specified in the 1974 RPA as requiring three tasks:

1. Summarize the current and historical inventory or production and use or consumption of timber, range, wildlife, fish, water, and recreation resources.
2. Project future multiresource inventory or production and use or consumption patterns from the current situation.
3. Analyze opportunities for improving the future resource inventory or production and use or consumption situation.

Tasks 2 and 3 both require analytical tools that can project the future supply and demand of the renewable resources by extending historic patterns (Task 2) and by constructing alternative futures (Task 3). Such analytical tools, or models, were needed for the 1989 assessment.

The objective of this research was to develop a model, based on current estimates of fish populations, that would be capable of projecting future fish production. The model and projections operated within a framework (Joyce et al. 1986), described below, intended to link multiple resources toward achieving the kinds of analyses prescribed in Task 3.

Landscape ecology recognizes the need for resource agencies to develop databases and management strategies at appropriate spatial scales to minimize problems of within-system heterogeneity (Risser et al. 1984). A national level model was not practical for resources, such as fish species, whose distributions are not national. Capturing sufficient detail about resource response to management for all lands across the United States has proven to be too cumbersome for one model that includes many different management activities on many ecosystems (Joyce et al. 1986). At the regional scale (i.e., several states), we can consider fewer ecosystem types, more similar in structure and function, than at the national scale. Within a region, we can address a common set of ecological and socioeconomic factors, which exert the most significant effect on likely future resource production (Joyce et al. 1986). Models developed at regional levels can be integrated across multiple resources to produce regional assessments and, ultimately, aggregated into a national assessment. The Forest Service Southern Region was selected for pilot development of regional models in a multiresource framework (Joyce et al. 1986) because potential conflicts among land use

[2] *Public Law 93-378. United States Statutes at Large. Volume 88, p. 476 (P.L. No. 93-378, 88 Stat. 476).*

[3] *P.L. No. 94-588, 90 Stat. 2949.*

requirements in the South had been identified (Alig 1984) and because multiple resource data were available. The South was divided into Southeast and South Central subregions based on Forest Service Forest Inventory and Analysis (FIA) units assigned to the Forest Service Southeastern and Southern Experiment Stations, respectively.

This report summarizes the current and historical populations and natural history of trout for the Southeast (Task 1). Although trout are present in the Appalachian mountain areas of the South Central subregion (Bivens et al. 1985), population data were not available, and the trout population analysis presented here is limited to the Southeast. Hereafter, region will refer only to the Southeast. Setting the context for development of the projection model, the next section outlines the multiple resource framework (Joyce et al. 1986) as it relates to the trout model structure, and briefly reviews models of trout-habitat relationships. The model we developed to capture regional trout-habitat relationships from the current situation is described, and model response under a baseline projection of the future is presented (Task 2). Although tradeoffs among all renewable resources are not considered in the analysis of alternative futures (Task 3), impacts of various timber management opportunities on the trout population are evaluated. Complete analysis under Task 3 requires analysis of habitat, user, and harvest attributes; some of those analyses will be addressed in other reports (e.g., Hof and Baltic 1988) and the 1989 assessment. Finally, implications for regional management of trout fisheries and research opportunities are discussed.

**Figure 1.—Present distribution of all trout species in the Southeast. The darkly shaded area represents the area surveyed by North Carolina and Virginia that constitutes the area for which the regional trout model was calibrated. The lightly shaded area shows where trout are known to occur but where no abundance data were available. Projections are made for both shaded areas.**

## CURRENT STATUS AND RECENT HISTORICAL TRENDS

### Current Resource Situation

Brook trout (*Salvelinus fontinalis*) are native to the Southeast, where their range extends into northeast Georgia (Lee et al. 1980). Rainbow trout (*Salmo gairdneri*) and brown trout (*Salmo trutta*) were introduced into coldwater streams of the region. During the late 1970's, several states in the Southeast made surveys of their trout resources. Virginia and North Carolina, the states with most of the trout streams in the region, made detailed surveys of trout abundance in streams that form the database for the research reported here. Georgia also supports a trout fishery, but abundances were not inventoried (Fatora and Beisser 1980). A very small corner of South Carolina has approximately 25 streams (200 miles) classified as coldwater habitat (USDI FWS 1983). Florida has no trout streams (fig. 1).

In Virginia, the 41 westernmost mountain counties support coldwater fisheries (Neal 1980). The state survey identified 2029 miles (446 streams) of wild trout streams, of which 67% were pure native brook trout, and an additional 946 miles of coldwater streams suitable for stocking (Neal 1980). Of this latter category, only 29% was actually trout fishery at the time of the survey (Neal 1980). Brook trout are scattered throughout the Virginia coldwater area, but predominate in three high-altitude physiographic regions: the Blue Ridge mountains, including Shenandoah National Park; the Blue Ridge plateau-Mt. Rogers area to the southwest, including parts of Jefferson National Forest; and the Allegheny highlands bordering West Virginia, especially on George Washington National Forest lands (Neal 1980). Wild rainbow trout (i.e., naturally reproducing) occur in about 20% of the trout streams, and wild brown trout in a very small number of streams (Neal 1980).

The North Carolina survey of 26 western mountain counties estimated that approximately 4000 miles of streams, at elevations over 1500 ft, were capable of supporting trout (Bonner 1983). Although trout abundance was determined in the trout stream survey, a state trout population estimate is not appropriate without an estimate of total habitat presently occupied.

Georgia classifies 2393 miles of primary trout streams, which contain naturally reproducing trout populations, and 1594 miles of secondary trout streams, which sustain nonreproducing trout year-round (Fatora and Beisser 1980). All trout streams are located in 31 counties of northern Georgia. The southernmost trout fishery in the Southeast is found in the tailwaters of the Buford dam on the Chattahoochee River, north of Atlanta (Hess

1980). Since the introduction of brown and rainbow trout, brook trout have disappeared from all but about 50 streams (87 miles), mostly in Rabun, White, and Union counties of Georgia (England 1979).

All Southeastern States (fig. 1), except Florida, stock trout. Both state and national fish hatcheries produce trout for stocking in the region. Regionally, more adult trout than fingerlings are stocked from the USFWS National Fish Hatcheries[4] in most years (fig. 2). Since 1965, fingerlings stocked have fluctuated between about 500,000 in 1965–1967 and 1985 up to nearly 2.5 million in 1980, while numbers of catchable trout increased from 1.2 million to about 2.0 million per year in the 1970's (fig. 2). Since 1983, stocking of both fingerlings and adults from the National Fish Hatcheries has declined, due to changes in distribution priorities.[4] Most stocked trout were rainbow trout, followed by brown trout (fig. 3). Georgia received most of the fingerlings stocked in the region during 1978–1980, and Virginia, relatively few; stocked adults were relatively evenly distributed among the 4 states, not in proportion to available habitat (fig. 4). Brown trout were not stocked in Virginia until the

[4]*United States Department of the Interior, Fish and Wildlife Service. Propagation and Distribution of Fishes from the National Fish Hatchery System, Report numbers 2-20 for fiscal years 1965 and 1966 through 1985.*

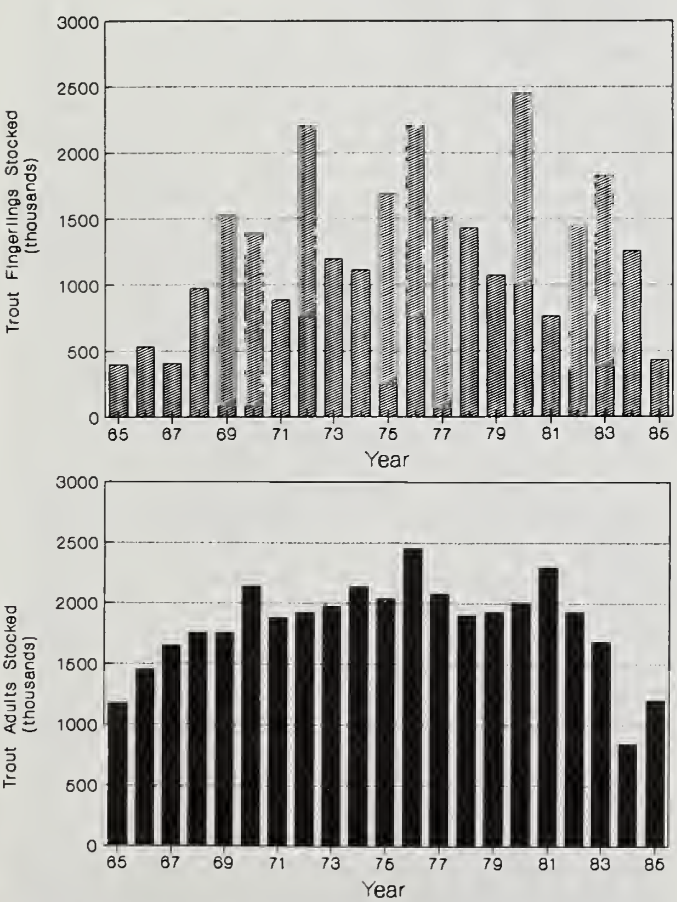


**Figure 2.—Numbers of (a) fingerling and (b) adult (sexually mature) trout distributed to Southeastern States from the USDI National Fish Hatcheries 1965-1985.[4]**

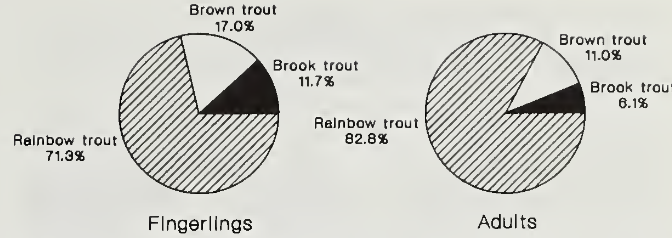


**Figure 3.—Percent of fingerling and adult trout distributed during 1978-1980 by species to the Southeastern States from the USFWS National Fish Hatcheries (Source: USDI FWS, Propagation and distribution of fishes from the National Fish Hatchery System).**

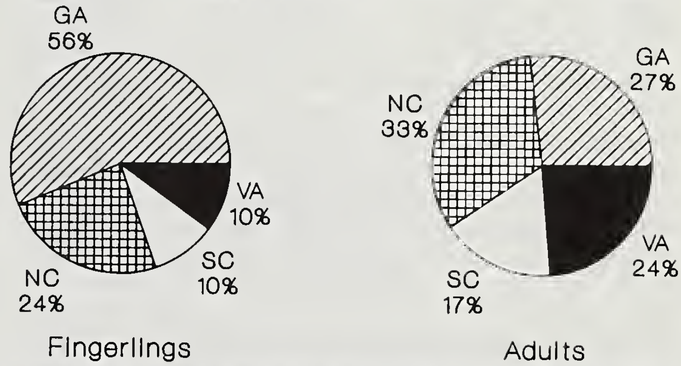


**Figure 4.—Percent of fingerling and adult trout distributed during 1978-1980 by state to the Southeastern States from the USFWS National Fish Hatcheries. No trout are distributed to Florida (Source: USDI FWS, Propagation and distribution of fishes from the National Fish Hatchery System).**

1960's, and continue to be a minor component (<6%) of state hatchery production (Neal 1980). In summary, the trout populations in the region are maintained by stocking, although, in the more northern and mountain areas of North Carolina and Virginia, more streams have reproducing populations, and stocking is less important (Neal 1980, Bonner 1983).

Both numbers of recreational freshwater fishing participants and their expenditures have been increasing nationally (table 1) (USDI FWS and USDC Bureau of Census 1982).[5] In 1980, 188,900 people fished for trout in Georgia, 204,300 in North Carolina, 45,800 in South Carolina, and 189,400 in Virginia.[6] By comparison, in the mid-1970's, trout anglers numbered 130,852 in North Carolina, 55,208 in South Carolina, and 133,662 in Virginia.[7] Trout license sales for Georgia have fluctuated between 87,000 and 100,000 during 1981–1984; North Carolina trout license sales have declined from 51,000 in 1981 to 45,000 in 1984; and Virginia trout license sales have increased from 112,000 in 1981 to 115,000 in 1984.[8]

[5]*Initial findings of the 1985 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation, U.S. Department of the Interior news release dated March 21, 1987.*

[6]*State reports for Georgia, North Carolina, South Carolina, and Virginia, prepared from the 1980 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation, U.S. Department of the Interior, Fish and Wildlife Service and U.S. Department of Commerce, Bureau of the Census, undated. 76 or 77 p. each.*

[7]*Data assembled for the 1979 assessment by the Forest Service from numbers provided by other federal agencies and the states.*

[8]*Vital Statistics for 1980, 1981, 1982, and 1984, compiled by the Southeastern Cooperative Fish and Game Statistics Project for the Southeastern Association of Fish and Wildlife Agencies.*

Table 1.—Trends for freshwater fishing participation and expenditures in the United States, 1965–1985. Expenditures per participant indexed to 1975 dollars with gross national product price deflators.

| Year | No. of participants (thousands) | Expenditures | |
|---|---|---|---|
| | | Total (millions) | Per participant (1975 dollars) |
| 1965 | 23,962 | $2,126 | $151 |
| 1970 | 29,363 | $3,734 | $175 |
| 1975 | 36,599 | $8,702 | $238 |
| 1980 | 37,081 | $14,441 | $274 |
| 1985 | 40,200 | $19,556 | $264 |

*Source: U.S. Fish and Wildlife Service and U. S. Bureau of Census, 1982.*[5]

On National Forests in the Southern Region, total coldwater fishing user days have increased from less than 600,000 in the late 1960's to nearly 800,000 in the early 1980's.[9] In general, trout fishing participants have increased in the past decade in the Southeast.

### Historical Resource Situation

Trout populations have not been inventoried systematically in the past for any large areas of the Southeast. Thus, the past history of trout populations cannot be described for the region in a quantitative manner.

The history of trout in the Great Smoky Mountains National Park in the southern Appalachian Mountains, on the border between North Carolina and Tennessee, has been analyzed. At the turn of the century, brook trout were found at elevations down to about 2000 feet in the area of North Carolina that was to become the Great Smoky Mountains National Park (King 1937). In the Smoky Mountains, rainbow trout stocking began about 1900 and became heavy after 1910 (Lennon 1967). By the 1930's, brook trout in the park area were restricted to headwaters above 3000 feet due to a combination of factors including logging, fires, overfishing, and stocking of rainbow trout (Powers 1929, King 1937). This restricted distribution continued to shrink with concomitant increases in rainbow trout distribution (Lennon 1967, Kelly et al. 1980, Larson and Moore 1985, Moore et al. 1986). In headwater streams, brook trout abundance is low and body size is small, suggesting a suboptimal habitat (Lennon 1967). Rainbow trout do not successfully invade the headwaters because a combination of factors limits their success: (1) presence of falls or cascades; (2) small stream water volume; (3) low temperatures, especially freezing temperatures in small streams; and (4) low pH (King 1937, Kelly et al. 1980, Moore et al. 1986). Zones of sympatry occur (Powers 1929, King 1937, Lennon 1967, Larson and Moore 1985, Moore et al. 1986). Overall, brook trout range in Great Smoky Mountains National Park was reduced by 70% by the mid-1970's (Kelly et al. 1980).

Similar changes have been reported for North Carolina, in general (Seehorn 1979). Since 1950, brown trout introduced at lower elevations in North Carolina have also migrated upstream, reducing the rainbow trout distribution (Kelly et al. 1980). Restoration projects in North Carolina and Georgia have found some recovery of brook trout populations after removal of rainbow trout (England 1979, Moore et al. 1983, Moore et al. 1986). In Virginia, brook trout appear to have been resistant to invasion by nonnative trout except for some invasion of rainbow trout in the southwest part of the state (Neal 1980). In Shenandoah National Park of northern Virginia, rainbow trout were reported to be limited in distribution and abundance (Lennon 1961).

## MODELING APPROACH

### The Multiresource Framework

Traditionally, fish have been related to their immediate environment, the stream. However, streams are imbedded within the landscape of the watershed, and the stream environment is affected by land use activities within its watershed. For multiple resource analysis and planning at the regional scale, fish habitat relationships in streams are not adequate, and the fish habitat must be extended to the watershed.

This research, to develop a modeling approach for regional analysis of fish resources, is part of a larger program, outlined by Joyce et al. (1986), for producing regional multiresource models toward a national assessment of renewable resources. This study is also designed to assess resource response to projected future land use and timber growth and yield in the Southern United States.[10] Fish, wildlife, forage, and water were identified as resources that depend on the same land base as does timber, and that might be affected by changes in land use and land cover patterns (Joyce et al. 1986).

To incorporate these other resources in the analysis, a multiple resource framework was designed (Joyce et al. 1986) that links forage, fish, wildlife, and water to the Southern Area Model (SAM) and Timber Resource Inventory Model (TRIM) (fig. 5). The Southern Area Model (Alig 1984) projects changes in acreages of cropland, range and pasture land, human land uses (urban, roads, farm structures, etc.), and major forest cover types (upland hardwoods, lowland hardwoods, mixed oak-pine, natural pine, and planted pine) for each state in the Southeast. On forest cover type acreages projected for the Southeast by SAM, TRIM simulates timber growth and yield to reflect timber management decisions (Tedder 1983, Tedder et al. 1987) required to meet harvest demands from a Timber Assessment Market Model (TAMM) (Adams and Haynes 1980). TRIM produces timber stand inventories for homogeneous cells that represent all stands of a given forest cover type, age class, ownership, site class, and stocking class. The three policy models (TAMM, TRIM, and SAM) make projec-

[9]*U.S. Department of Agriculture, Forest Service, Wildlife and Fish Habitat Management in the Forest Service for Fiscal Years 1967 through 1984, Washington, D.C.*

[10]*The South's Fourth Forest: Alternatives for the Future, draft document, USDA Forest Service, Washington, D.C., 1986. 365 p. + appendices.*

tions of the future land use acreages and timber inventories for baseline and alternative scenarios.

The other resource models (fig. 5), including the fish model, are intended to evaluate the effects of the land use changes and timber management on their respective resource. The resource models are linked by the common land base. In this framework, common land base refers to the common description in terms of land use and timber resource described above, rather than the more stringent requirement that all models operate on the same geographic unit (e.g., Forest Service region, state, county, watershed). Each resource operates on the geographic unit that is logical and appropriate for the resource, and all geographic units listed above are represented in the framework. For the fish resource, a watershed unit is the most appropriate geographic unit for three reasons: (1) a watershed unit allows the model to capture the relationship between trout and habitat at a regional scale; (2) the immediate environment for trout is the stream, and watersheds are the associated land unit for streams; and (3) the watershed unit, the geographic unit of the water quantity model, allows changes in water yield to be incorporated in the fish response. The watershed unit provides the means for incorporating both direct and indirect impacts of land base changes. Within the multiresource framework (fig. 5), there is no analysis of how management for fish influences timber; thus, this is an impacts analysis for fish. The analysis will identify changes in the land base that may create changes in the fish population.

The objective for this research, stated above, was refined to include the requirement that the analytical tool must operate within the framework just outlined: To develop a regional model based on current estimates of trout production that is capable of projecting future trout production from projected changes in land use and the timber resource within the multiple resource framework (fig. 5).

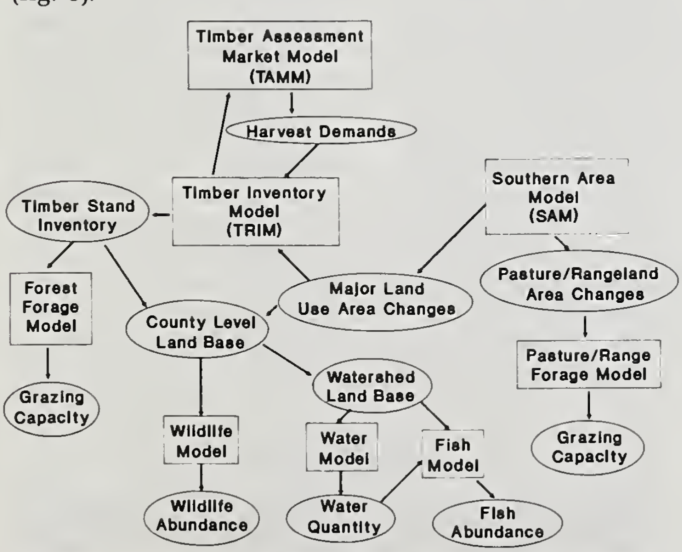


Figure 5.—Multiple resource model framework for linking individual resource models at the regional level. Boxes are models and ellipses are databases and model outputs. Arrows represent information transfers among resource models. (After Joyce et al. 1986.)

## Trout Habitat Models

Few regional models, on the scale of several thousands of square miles, that relate fish abundance to land use and forest cover in the watershed habitat have been developed. Even site-specific stream models that predict fish abundance from habitat characteristics are rare compared to terrestrial wildlife habitat models (Hawkes et al. 1983). A few habitat models, such as the Fish and Wildlife Service Habitat Evaluation Procedures (HEP) (USDI FWS 1980), make predictions for current habitat conditions but predict suitable habitat rather than fish populations. In an analysis of streams in the southern Appalachian Mountains of North Carolina and Tennessee, the null hypothesis of no relationship between trout abundance or biomass and HEP physical habitat indices (e.g., weighted usable area, WUA) was rejected for some species' life stages (Loar et al. 1985). These habitat models do not include biological interactions between species and may not be appropriate to all management questions (Loar et al. 1985).

Multivariate statistical techniques are particularly well suited for habitat analyses (Shugart 1981) and, properly designed, can produce resource predictions. Some local level stream models have implemented statistical procedures, commonly correlation or regression analysis, to predict present fish population size in a stream from a suite of biologically or ecologically meaningful variables. For example, Binns and Eiserman (1979) modeled Wyoming trout stream standing stock with 10 factors that measured various aspects of flow, temperature, nitrogen, substrate, cover, and stream width. Burton and Wesche (1974) identified stream flow and watershed drainage, elevation, forested area, and total basin stream length as factors significantly related to trout standing stock in nine Wyoming streams and rivers. Harshbarger and Bhattacharyya (1981) used factor analysis to identify cover variable factors for small trout streams in western North Carolina and used regressions to relate these factors and the original variables to trout standing stock.

Site-specific models of trout abundance were deemed inappropriate for the national scope of the RPA assessment (Hawkes et al. 1983). Models developed for one spatial scale (e.g., a stream) cannot generally be applied to another disparate scale (e.g., the Southeast) (Risser et al. 1984). Available site-specific models of trout abundance also suffer one or more of the following disadvantages:

1. Models require detailed stream habitat data not available in state or regional inventory databases (e.g., stream cover, substrate, bank condition, Harshbarger and Bhattacharyya 1981).
2. Independent (predictor) variables are not related to land use or water quantity variables that link resource models to policy models in the framework of figure 5.
3. Models were developed for streams geographically removed from the Southeast and are not transferable (e.g., Binns and Eiserman 1979, Burton and Wesche 1974).

To overcome the first two disadvantages and implement these models in the regional framework outlined above would require intervening models that relate inventory descriptions and land projections to stream habitat characteristics. A direct approach is preferred. Transferring models from other regions of the country is not feasible because those models are specific to the issues appropriate to their region and not to the objectives of this analysis.

The goal of the trout model is to produce a regional predictive model of the fish resource based on current land use, timber cover, and water quantity. Because we have no known functional, or mechanistic, relationships between land use or water characteristics and fish production at this scale, we have chosen a statistical approach to the problem. The approach is similar to one used for regional wildlife models (Klopatek and Kitchings 1985, Flather et al. in press). An appropriate sampling unit must first be selected with a statistical approach. Ideally, sampling units are small enough to minimize problems of spatial heterogeneity in landscapes (Risser et al. 1984) and to provide sufficient sample size for multivariate analysis. In the framework described above, the fish resource model is linked to a water quantity model that projects runoff for watersheds above U.S. Geological Survey (USGS) gauging stations. To implement the linkage, the same watersheds were used as sampling, and geographic, units for the trout model.

To establish statistical relationships between trout abundance and land use, timber cover, and runoff, we chose to use discriminant function analysis rather than a multiple regression model because a discriminant function model minimizes the impact of several data assumptions we made (discussed below). Discriminant function analysis has been used to produce statistical models for both descriptive and predictive purposes (Williams 1983). This trout model uses a discriminant function analysis to develop a classification from the land and water data, capable of predicting trout abundance class membership from land use and water quantity projections.

## REGIONAL TROUT MODEL

### Water and Land Area Databases

The U.S. Geological Survey gauges define the watersheds for the trout model. Watersheds were selected from the set of USGS gauging stations by a number of criteria intended to meet three major objectives: (1) high-quality flow data were obtained during 1977 and for at least 5 years during 1973–1983; (2) no watersheds were nested in others; and (3) watersheds between 100 and 700 square miles in area, roughly the size of counties from which the land base is derived, were preferred. The total range of watershed size for the coldwater fish model was 39 to 3050 square miles; but, 85% of the watersheds fell in the 100–700 square mile range. Watershed sizes were distributed uniformly across trout abundance classes.

Annual average instantaneous flows (cubic feet per second) recorded by the USGS gauges over the period 1973–1983 were converted to acre-feet per acre-year to standardize for drainage area and to produce a measure that could be applied to the watershed as a unit. Thus, water quantity is a measure of runoff (ft/yr).

The watershed land use and land cover data were derived from county land use and land cover data obtained from the Soil Conservation Service (SCS) National Resource Inventory (NRI) (USDA SCS and Iowa State University Statistical Laboratory 1987) and the Forest Service Forest Inventory and Analysis (FIA) (USDA FS 1985) surveys. Estimates of total county land and water area were obtained from the U.S. Bureau of Census (USDC Bureau of Census 1970). The FIA inventory provided area estimates of commercial forestland for forest cover types (natural pine, planted pine, oak-pine, upland hardwood, and lowland hardwood) and forest age class; the NRI inventory supplied estimates of all other land types (crop, pasture, range, and human land uses). Combining the FIA and NRI inventories to characterize total county land area resulted in discrepancies when compared with Bureau of Census estimates of total county area because the two inventories are not mutually exclusive. The FIA and NRI databases were adjusted by iterative proportional fitting (Deming and Stephan 1940), called "raking," to approximate total county land area reported by the Bureau of Census. Proportions of each county contributing to each watershed were determined by planimetry or extracted from a digitized database of county-USGS Hydrologic Cataloging Unit intersections.[11] Acres from each county-watershed intersection were summed for each watershed by land use, then converted to proportions of each watershed in the NRI land use and FIA land cover categories.

The NRI and FIA categories were aggregated into the commonly defined land use and land cover categories to form, with USGS runoff estimates, the suite of independent variables that describes the current land base and runoff for the model (table 2). In this current inventory (1982), the coldwater watersheds, in the Appalachian Mountains and higher areas of the Piedmont, have very little planted pine (1.1% of the current inventory land base) and lowland hardwood forest (0.5%)—two forest types that are much more common in other areas of the Southeast region. Natural pine forest (9.9%), human land use (7.2%), and cropland (4.8%) are also less common in the coldwater area. In contrast, pastureland (18.9%), total forestland (65.5%), mixed oak-pine (8.0%), and, particularly, upland hardwood forests (45.9%) are more common than in the Southeast as a whole. Most of the additional acreages of upland hardwoods are in the two older age classes.

### Fish Database

Regional fish models are limited by the availability of suitable databases. In most cases, data were collected by state agencies for various purposes, and adjustments

[11] *Computer tape and documentation produced by Robert G. Edwards and others, Oak Ridge National Laboratory, Oak Ridge, TN, 1983.*

Table 2.—Definition of independent variables used to develop the regional trout model. RUNOFF was transformed by natural log, and land use and land cover variables were proportions transformed by arcsine-square root to meet the normality assumption.

| Variable acronym | Variable definition |
|---|---|
| RUNOFF | average over 1973–1983 of mean annual flow (acre-ft $acre^{-1}$ $yr^{-1}$) |
| TOTCRP | total cropland, including estimates of row crops, close grown crops, horticultural crops, unplanted crop land, and other crop land |
| TOTPAST | total pasture land and range land, including estimates of pasture, range, and rotation hay and pasture |
| HUMAN | total land associated with human development, including estimates of urban land, roads, railroads, stripmines, and farm structures |
| NP | total estimates of natural pine |
| | estimates of natural pine by age class |
| NPA1 | age class 1: 0–20 years |
| NPA2 | age class 2: 21–50 years |
| NPA3 | age class 3: 50+ years |
| PP | total estimates of planted pine |
| | estimates of planted pine by age class |
| PPA1 | age class 1: 0–10 years |
| PPA2 | age class 2: 11–30 years |
| PPA3 | age class 3: 30+ years |
| OP | total estimates of oak-pine |
| | estimates of oak-pine by age class |
| OPA1 | age class 1: 0–20 years |
| OPA2 | age class 2: 21–50 years |
| OPA3 | age class 3: 50+ years |
| UH | total estimates of upland hardwood |
| | estimates of upland hardwood by age class |
| UHA1 | age class 1: 0–20 years |
| UHA2 | age class 2: 21–50 years |
| UHA3 | age class 3: 50+ years |
| LH | total estimates of lowland hardwood |
| | estimates of lowland hardwood by age class |
| LHA1 | age class 1: 0–20 years |
| LHA2 | age class 2: 21–50 years |
| LHA3 | age class 3: 50+ years |
| AGE1 | estimates for age class 1 across all forest types except planted pine |
| AGE2 | estimates for age class 2 across all forest types except planted pine |
| AGE3 | estimates for age class 3 across all forest types except planted pine |
| HWAGE1 | estimates for age class 1 across hardwood types (oak-pine, upland hardwood, lowland hardwood) |
| HWAGE2 | estimates for age class 2 across hardwood types (oak-pine, upland hardwood, lowland hardwood) |
| HWAGE3 | estimates for age class 3 across hardwood types (oak-pine, upland hardwood, lowland hardwood) |

were necessary to match these data to our model objectives. Commonly, state databases stratify the region into coldwater and warmwater fisheries, thereby eliminating a major source of regional variability and orienting the analysis to specific fish resources. For this pilot study, state surveys of trout streams in North Carolina (Bonner 1983) and Virginia (Neal 1980)[12] were selected because the state agencies had recently collected data with similar methods, and because these two states comprise the greatest extent of trout fisheries in the Southeast (fig. 1). All three species of trout—brook, brown, and rainbow trout—are present in these waters; however, in the model no distinction is made between species. By using total trout abundance, interspecific competition becomes less important as a factor structuring population estimates.

In these two surveys, state-designated trout streams were typically sampled once by single-pass electrofishing a 200–500 ft length of stream (Neal 1980, Bonner 1983),

[12]*Computer tape of the Virginia Stream Survey Retrieval System was obtained from the Department of Fisheries and Wildlife Sciences, Virginia Polytechnic Institute and State University, Blacksburg, VA.*

although in Virginia longer samples were taken where efficiency was low. A given stream was sampled in several reaches, and in North Carolina, a given reach was sampled on several different dates. No attempt was made to consolidate replicate samples. A total of 1311 stream samples from the mountain areas of North Carolina (537 streams sampled 1978–81) and Virginia (744 streams sampled 1975–79) comprise the coldwater fisheries database.

Both state surveys recorded numbers of each trout species in samples; however, some assumptions were necessary to convert the original numbers in samples into standardized area-based estimates (trout per acre of stream). For Virginia, we assumed the electrofishing probe rig sampled a maximum of 10 ft of stream width.[13] In North Carolina, a probe was used for smaller streams and 15- and 30-ft electric seines were used in larger streams (Bonner 1983). Although the different rigs probably had different success rates, we assumed the same success rate and made the following additional assumptions for North Carolina streams: in streams up to 15 ft and 20–30 ft in width, the entire stream width was sampled; 15 ft of width was sampled in streams 15–20 ft wide; and 30 ft of width was sampled in streams over 30 ft wide.[14]

The streams sampled for trout were located within the USGS gauged watersheds. Only 620 of the 1311 streams sampled had both trout present and were located within the gauged watersheds. Thus, the 60 watershed sample units used to build the model represent a sample of the coldwater area outlined in figure 1, limited by the overlap of trout-containing stream samples with USGS gauged watersheds.

Within watersheds, many stream samples contained no trout. Absence of trout in a sample is an ambiguous condition (we cannot determine whether there were no trout or whether trout were present but not captured), and incorporation of zero density in the data sets for individual watersheds creates a statistically intractable distribution. Therefore, all stream samples with a trout density of zero were eliminated, and the trout model predicts trout density (number per unit area) in those streams that do have trout. After the streams with no trout were eliminated from the database, the abundance estimates were found to be log-normally distributed within watersheds, and the density estimate for watersheds was the geometric mean of stream trout densities. To minimize errors that might result from assumptions made to calculate density, numerical estimates were converted into three abundance density classes. Twenty watersheds in the low density class had at least 1 individual up to 100 trout per acre of stream; 19 moderate density watersheds had 100–160 trout/acre; and 21 high density watersheds had more than 160 trout/acre. In the frequency distribution of abundances (i.e., geometric mean of abundance for each watershed), the high class forms a distinct peak. No such distinction clearly separates the low and medium abundance classes, and the boundary between these classes was selected to block for a confounding factor, physiographic strata. The watersheds in the fish model fall within both the Appalachian (43 watersheds) and Piedmont physiographic strata (17 watersheds). Preliminary analysis determined that land use and forest cover were significantly different between these two strata ($p < 0.05$). With the boundaries between abundance classes set as stated above, the numbers of watersheds in each stratum were distributed relatively equitably across abundance classes (Appalachian, 15, 13, 15; Piedmont, 5, 6, 6; total, 20, 19, 21; low, moderate, high, respectively).

In this analysis, we assume that the trout samples were synoptic; in the context of 50-year projections, the 7-year span of sampling is effectively synoptic. We further assume that the predictor variables, runoff and land use and land cover, are temporally associated with the trout estimates to describe the current relationships. The USGS flow data for 1973–1983 accomplish the temporal linkage between trout estimates made in 1978–1981 and the NRI survey in 1982 and FIA surveys in 1984 for North Carolina and 1977 for Virginia. Thus, trout, runoff, and land use and land cover are both spatially and temporally linked by the USGS watersheds to provide a basis for a statistical landscape model.

**Model Development**

Discriminant function analysis was used to develop a classification from the land and water data, capable of predicting trout density group membership from land use and water quantity projections. Linear discriminant function analysis is sensitive to two assumptions about the data, multivariate normality of independent variables within classification groups and homogeneity of covariance matrices among classification groups (Morrison 1967). Ecological data tend to violate these two assumptions, especially the latter, and particularly compromise results when used for descriptive purposes (Williams 1983). We chose to use the Statistical Analysis System (SAS Institute Inc. 1982a, 1982b) package because the UNIVARIATE procedure tests for univariate normality (Shapiro-Wilk statistic), and the DISCRIM procedure allows the user to test for homogeneity of covariance matrices and produces a quadratic discriminant function if the homogeneity test fails.

To meet the normality assumption, a natural logarithmic transformation of runoff and arcsine-square root transformations of land use proportions were necessary. Several land use variables were eliminated because the normality assumption could not be met after transformation. In this analysis, because sample sizes are small, a subset of the remaining independent variables must be selected. The variables were selected to be relatively uncorrelated and to produce the best discrimination among classes. Instead of using a statistical (e.g., stepwise) procedure to select variables, which introduces attendant problems (Habbema and Hermans 1977, Johnson 1981),

[13] *Based on personal conversation with Larry O. Mohn, Virginia Commission of Game and Inland Fisheries, Staunton, Virginia, 1986.*

[14] *Based on personal conversation with Wayne Jones, North Carolina Wildlife Resources Commission, Division of Inland Fisheries, Waynesville, North Carolina, 1986.*

the following procedure was followed: The transformed independent variables from table 2 that passed the normality test were grouped to minimize correlations among variables. Candidate models were constructed by a sequential elimination of variables from each group of variables. The test for homogeneity of covariances among trout density classes nearly always failed, and the SAS discriminant analysis proceeded with the nonlinear quadratic form. The model with the minimum number of independent variables and with the maximum reclassification success (percentage of watersheds that are correctly classified in a reclassification by the model) was selected (Habbema and Hermans 1977).

The selected model (table 3) classifies trout density class as a quadratic discriminant function of seven independent variables, RUNOFF, TOTCRP, HUMAN, NPA1, NPA2, HWAGE2, and HWAGE3, with a reclassification success of 78.3%. In this model, high trout density is associated with the highest coverage of old-age hardwoods (HWAGE3) and the lowest proportion of land devoted to human uses (HUMAN) and cropland (TOTCRP) (table 3). Lowest trout density was associated with highest proportion of human land uses. Implicit in these relationships are factors such as water temperature, sediment load, instream cover, food resources, and shading that are favorable for trout in areas with old hardwoods (Sedell and Swanson 1984) and are unfavorable for trout in areas with large amounts of human land use.

## MODEL APPLICATION

For regional projections of the trout resource, the discriminant function analysis results were extended into areas of northern Georgia and extreme northwestern South Carolina where trout are known to occur but where abundance data were lacking. Fourteen watersheds were added to the original 60 from Virginia and North Carolina (fig. 1).

Regional projections of land use and forest types for 1985 through 2030 from the land area model (Alig 1984) and timber growth and yield model (Tedder 1983, Tedder et al. 1987) were applied to the discriminant function analysis model to produce an analysis of a likely future for the trout resource (the baseline scenario) and several alternative scenarios (see Appendix). Projected land use and land cover acreages for the years 1985, 1990, 2000, 2010, 2020, and 2030 were converted to proportions of each watershed by the raking method described above. In effect, changes projected for each time step were allocated among states, counties, and watersheds in proportion to the area present at the beginning of each time step. Before raking, site class and stocking class cells projected by TRIM were collapsed into cover type and age class cells by ownership. Although not explicit in the trout model, ownership (national forest, other public, forest industry, and other private) was tracked because current and projected timber management behavior varies among owners, and distribution of ownerships also varies across the Southeast. For example, most of the National Forests of the region are in the higher elevations and retain older age classes of forest. The forest industry and other private owners, which predominate in other areas of the Southeast, are assumed by TRIM to cut younger age classes of both pine and hardwood forest types than do federal owners.[10]

Land use and forest cover type projections were made for the entire Southern United States. In the following discussions and figures, data are given only for the watersheds that comprise the coldwater area of the Southeast; therefore, the land base description will differ from that reported elsewhere (Flather et al. in press, Joyce in press).[10]

For a watershed, yield (ft/year) was predicted as a function of the proportion of watershed land area in different

Table 3.—Results of quadratic discriminant function analysis; (a) mean (standard error) transformed value of each predictor variable for each trout abundance class; and (b) final classification summary table for the calibration data, number of observations from original class (rows) classified into column class (% of original class).

A.

| | Trout abundance class | | |
|---|---|---|---|
| Predictor variable | Low | Moderate | High |
| RUNOFF | 0.572 (0.066) | 0.622 (0.076) | 0.620 (0.095) |
| TOTCRP | 0.202 (0.019) | 0.219 (0.026) | 0.186 (0.019) |
| HUMAN | 0.280 (0.014) | 0.251 (0.014) | 0.244 (0.012) |
| NPA1 | 0.123 (0.021) | 0.109 (0.019) | 0.115 (0.014) |
| NPA2 | 0.196 (0.025) | 0.179 (0.023) | 0.161 (0.017) |
| HWAGE2 | 0.473 (0.019) | 0.483 (0.020) | 0.447 (0.023) |
| HWAGE3 | 0.552 (0.025) | 0.539 (0.034) | 0.618 (0.035) |

B.

| | To class | | |
|---|---|---|---|
| From class | Low | Moderate | High |
| Low | 17 (85) | 2 (10) | 1 (5) |
| Moderate | 4 (21) | 12 (63) | 3 (16) |
| High | 1 (5) | 2 (10) | 18 (86) |
| Total | 22 | 16 | 22 |
| Percent of total | 37 | 27 | 37 |

land use and forest cover categories and runoff estimates based on literature and expert opinion.[15]

Trout density for the Southeast region was estimated as follows. Classification produces a posterior probability of membership in each of the three classes for each watershed; averaged over all watersheds, those probabilities become regional probabilities for each class. Regional probabilities were not weighted by watershed size because the trout densities of large watersheds would be inappropriately emphasized over those of small watersheds. Trout streams are distributed relatively uniformly within small watersheds. However, as watershed size increases, higher order streams that do not support trout are included in the watershed, and trout streams are found in only a portion of the watershed. The very largest watersheds in the model contain a large number of trout streams, but also include acreage that is not in the coldwater area. Expected densities of 50, 130, and 363 trout/acre (the midpoints of each class) were assigned to the low, moderate, and high density classes, respectively. Average regional probabilities were multiplied by these expected densities and summed to obtain a single, regional estimate of trout density (number per acre of trout stream).

## Ecological Assumptions

Several assumptions were made in model development and application. These assumptions should be considered when interpreting the model results and applications.

Few sampling programs have been designed with regional analysis as an objective. The North Carolina and Virginia data sets provided a rare opportunity to analyze a relatively large geographic area. Nevertheless, several aspects of the state fish sampling programs require assumptions be made for the analysis: The estimates of trout density are based on trout captured by single-pass electrofishing. Furthermore, similar capture efficiencies were assumed, regardless of stream size and some differences in sampling rigs. Thus, the projected trout densities are those that would be perceived with future sampling programs designed around similar methods. The size distribution of trout in the stream samples was unknown and assumed to be similar across trout density classes. Abundance estimates represent summer populations because sampling surveys were generally made between May and September. Trout density estimates apply to accessible trout streams in the coldwater area. A different data base and analysis would be required to include all streams because the states sampled only streams likely to have trout that were accessible, both legally and physically (Bonner 1983).

Stocking is practiced by both states, but in both cases, the trout sampled represent populations capable of surviving throughout the year. Trout and stream habitat management are not explicit in the analysis. To the extent that these management practices determine trout density at the time of sampling, trout management actions are implicit in the analysis. In the projections, stocking and other trout management practices (e.g., riparian zone management, stream structures) are assumed to continue in the future at the level practiced in the 1970's and early 1980's.

All factors that affect trout abundance and are external to the relationship between trout and the watershed land base are also assumed to be constant both across watersheds and through the projection period. For example, competition between trout and other fish species is assumed constant. Some factors that affect trout (e.g., point sources of pollution and water treatment) are inherent in human land use, and the implied relationship between trout habitat quality and human land use is assumed constant. The rate of trout harvest is also linked to human land use, and the linkage is assumed constant throughout the region and through time.

In constructing the land base, counties were assumed to be homogeneous; that is, the proportion of each land use and forest type applies to all partitions of the county. When parts of counties were reallocated to watersheds, homogeneity within the watershed was also assumed, so that the land uses and forest types could be related to the trout density class for that watershed.

Annual runoff was calculated from flow records at the base of the watershed for the 1973–1983 period. In the analysis, runoff measured at the base of the watershed is assumed to apply to the watershed as a whole. For example, if the runoff for a watershed is 2 ft/year, the amount of water spread 2 ft deep over the entire watershed runs off in each year. From the perspective of trout, the assumption is that increases or decreases in runoff will be reflected in increases or decreases of flow in trout streams. In the projections, future precipitation will average the same as it was in the 1973–1983 period, and changes in runoff are assumed to be due solely to land changes. That is, no additional water management programs, such as damming or diversion, will be implemented. Also, the projections assume that increased runoff will be spread uniformly throughout the watershed.

The watersheds used to calibrate the model are a sample of the land base, dependent largely on the location of USGS gauges monitored more or less continuously during 1973–1983. The sample is also dependent on location of at least one trout stream, as defined by the fish database, within each gauged watersheds. The sample is 40–50% of the coldwater area and is assumed to be random and representative of the Southeast coldwater fishery.

In applying the projections, regional and state level changes are allocated to counties based on the relative size of each county and the relative importance of each land use or forest type in the county. The resulting county land base is proportionally allocated to watersheds. Thus, regional changes in a given land use or forest type are assumed to apply to all counties and watersheds in proportion to the amount of land in that type. Furthermore, the trout density relationship to land use, forest

[15]*The South's Fourth Forest: Regional Water Response to Timber Management, unpublished report by Stan Ursic, USDA Forest Service, Forest Hydrology Laboratory, Southern Forest Experiment Station, Oxford, MS, 1986. 21 p. + appendix.*

type, and runoff established for Virginia and North Carolina watersheds is assumed to apply to northern Georgia and northwestern South Carolina watersheds.

### Baseline Scenario

The baseline projection describes the timber situation, provided that assumptions about supply and demand are realized.[10] Present expectations about human population growth, economic activity, income, and product prices determine expected demand, while changes in the area of timberland, timber management intensity, timber growth, and stumpage prices determine future supply under the baseline scenario. A number of timber-related assumptions were incorporated in the projection, including a level of timberland management that was more intense than current management.

Under the baseline scenario, increasing human population results in an increase of land devoted to direct human land use (from 7.5% in 1985 to 9.8% in 2030). In the coldwater area, cropland and pastureland uses remain nearly constant over the period. Total forestland declines from 64.6% to 62.2% between 1985 and 2030. Natural forest types, especially natural pine, are converted to planted pine in the baseline run; however, because planted pine is rare in the coldwater area (1.5% of the land base in 1985), total planted pine increases to only 3.2% in 2030. The oldest age classes of natural pine, oak-pine, and upland hardwood forest decrease as the forests undergo a harvest, but increases in the youngest age class indicate regeneration of the same forest type.

Among the land use and timber variables in the trout projection model (fig. 6), the proportion of old-age hardwoods (HWAGE3) in the land base declines most dramatically after 2000. Middle-age hardwoods (HWAGE2) decline through 2010, but this decline largely represents growth and aging of stands to the old age class. Total hardwoods decline only slightly (from 54.2% to 53.2% in 2030) over the projection period; however, the age structure changes dramatically as older hardwood stands are cut and regenerate over time. In the natural pine age classes, the dynamics between young (NPA1) and middle (NPA2) age classes also represent a cycle of cutting and regrowth (fig. 6). The importance of natural pine in the coldwater area land base is minor, and these small changes, relative to those in hardwood age classes, are not likely to exert a large influence on trout density. Cropland remains nearly constant throughout the projection period, and human land uses increase predictably (fig. 6). Over the projection period, annual runoff increases by about 1 inch per year (fig. 6).

These projections of land use and forest type age classes and of runoff result in a decrease of 47 trout/acre from the 1985 density of 173 trout/acre (fig. 7, table 4), corresponding to a 27% decline between 1985 and 2030. The decline of trout abundance is largely in response to the decline of old-age hardwoods (over 50 years of age) and increased human land use over the projection period. As older hardwood acreages decline over time, shading declines and water temperature increases. At the same time human land use is increasing at the expense of higher quality trout habitat. Trout density declines under these land use and forest cover changes and the attendant modification of trout habitat.

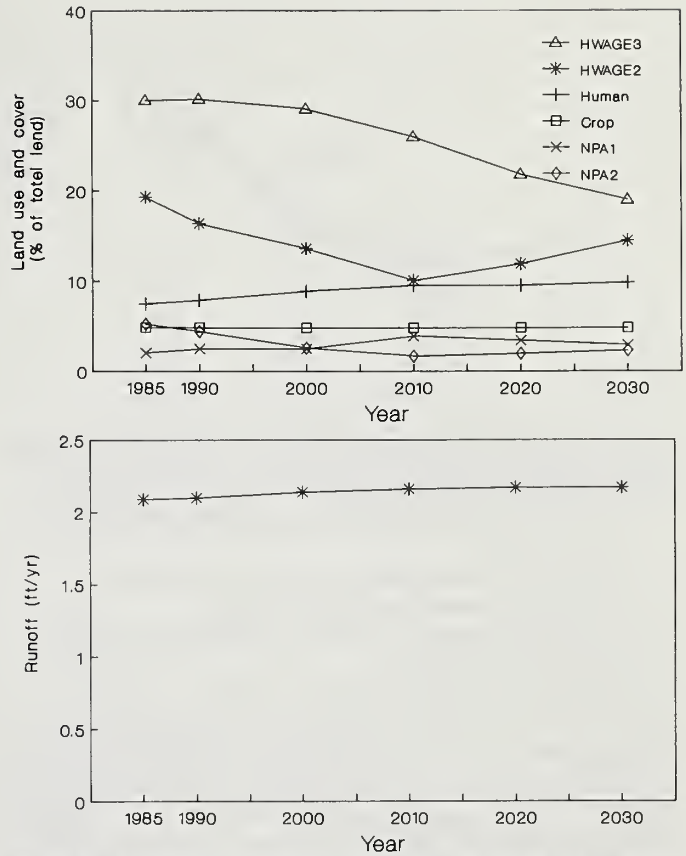

**Figure 6.—Baseline projections for trout density predictor variables: (a) percent of land uses and cover types in coldwater area over the baseline projection; and (b) feet of runoff per year in the coldwater area over the baseline projection.**

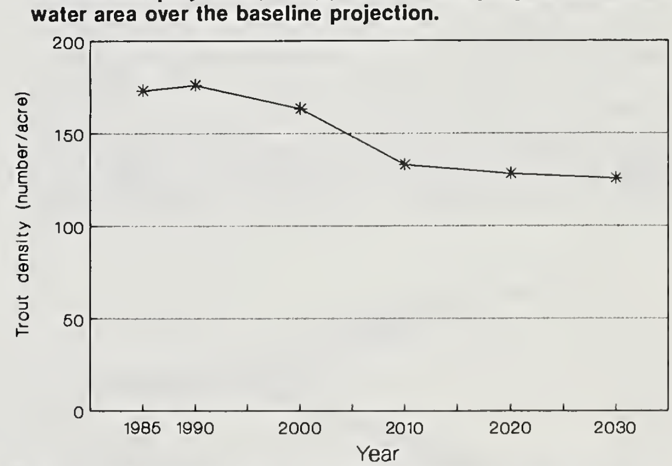

**Figure 7.—Baseline projection of trout density (number per acre of trout stream in watersheds) for the coldwater area. The overall decline is 27%.**

### Alternative Scenarios

In the Southern Timber Supply Study, several alternative futures were considered (see the Appendix for a description of the assumptions behind each scenario).

Table 4.—Trout density (number/acre of trout stream) for Southeastern coldwater watersheds under baseline and alternative scenarios.

| | Baseline | Increased stumpage cost 7 | Reduced timberland area 8 | Reduced timber growth 9 | Reduced NF harvest 10 | Economic opportu-nities 13 |
|---|---|---|---|---|---|---|
| 1985 | 173 | 173 | 173 | 173 | 173 | 173 |
| 1990 | 176 | 176 | 178 | 177 | 178 | 174 |
| 2000 | 163 | 162 | 173 | 168 | 168 | 156 |
| 2010 | 133 | 130 | 156 | 135 | 129 | 127 |
| 2020 | 128 | 124 | 155 | 128 | 119 | 126 |
| 2030 | 126 | 122 | 155 | 123 | 119 | 124 |

We analyzed the five scenarios that produced changes in the commonly defined land base for impacts on trout density with the trout model:

7. Increased stumpage costs over those in the baseline run;
8. Reduced timberland area by conversion of marginal timberland to cropland;
9. Reduced timber growth for natural pine, planted pine, and oak-pine;
10. Reduced National Forest harvest;
13. Economic opportunities on private timberland.

These scenarios were developed to test alternative timber management strategies, and variations in land use and timber cover among the several scenarios were small. The scenarios were not designed to represent land use and forest cover changes that could be significant for the trout resource. Consequently, the variation in trout density was smaller among scenarios than the change observed over the projection period in the baseline and all scenarios. Trout densities projected for 1985 under all scenarios were nearly identical (table 4); to make comparisons among scenarios more effective (fig. 8), all projected densities were indexed to the corresponding 1985 density (from table 4). Likewise, in figures 9–14, land uses and cover are indexed to the 1985

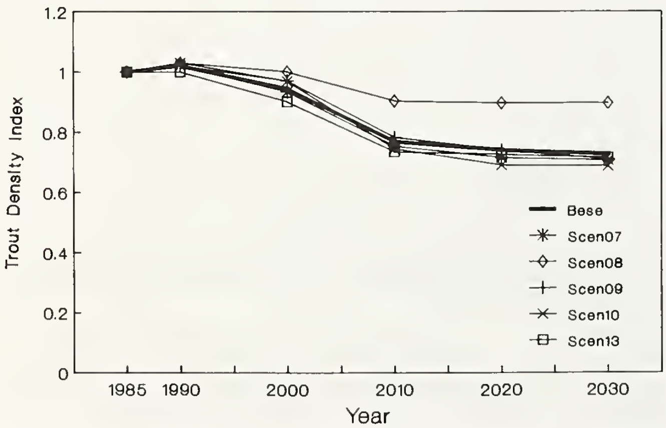


**Figure 8.—Comparison of trout density index among baseline and alternate scenarios for Southeastern coldwater watersheds. Index is the ratio of trout density in a given year for a given scenario to the 1985 density under the same scenario. Scenarios are numbered: Increased Stumpage Costs (Scenario 7), Reduced Timberland Area (Scenario 8), Reduced Timber Growth (Scenario 9), Reduced National Forest Harvest (Scenario 10), and Economic Opportunities on Private Timberland (Scenario 13).**

value. Runoff does not vary among scenarios. In the following discussions of the individual scenarios, only deviations of each scenario from the baseline will be discussed.

## Increased Stumpage Costs

Although softwood inventories build under this scenario of increased stumpage costs, the proportion of land in young and middle-age natural pine and middle- and old-age hardwoods is nearly the same as the baseline (figs. 11–14). After 2010, old-age hardwood acres drop below the baseline acres (fig. 14) and trout density also drops slightly (fig. 8). Trout density response under this scenario is nearly the same as the response under the baseline projection because management under this scenario does not shift acres of land use or forest cover types.

## Reduced Timberland Area

Conversion of timberland to cropland is spread over all forest types and ages, so that the proportion of land in forest type age classes differs from the baseline by only small amounts, especially when compared to the changes over time. In fact, for natural pine and hardwood age classes, this scenario diverges less from the baseline than do other scenarios (figs. 11–14). Human land use acres are very slightly higher at 2030 (fig. 10). The only large difference in the land base is increased cropland acreage (fig. 9). Although the increase in cropland in figure 9 appears dramatic, this increase represents a small change in cropland from 4.9% of total land in 1985 to 6.6% in 2030. The changes in acreage of both forest type age classes and land uses combine to produce a smaller decline in trout density compared to the baseline decline (fig. 8). Under this scenario, increased cropland acreage is not a factor that increases trout density, but a factor that moderates the decline of trout in the context of increasing human land use and decreasing old-age hardwoods. Trout density declines because old-age hardwood acres decrease and human land use acres increase as much as in the baseline projection, and trout habitat is degraded with those changes. The reason for a more moderate decline under this scenario of increased crop-

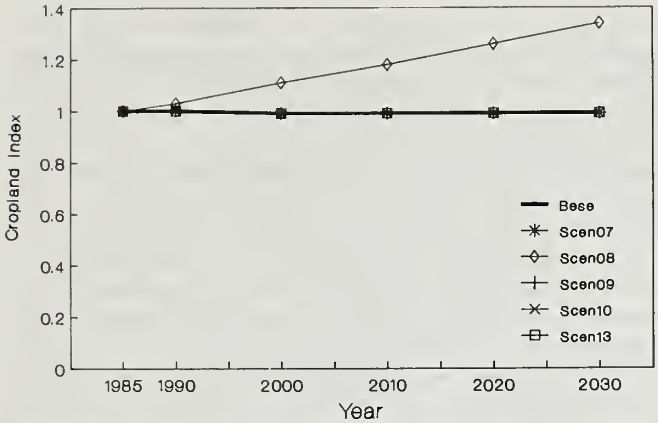


**Figure 9.**—Comparison of total cropland among baseline and alternate scenarios for Southeastern coldwater watersheds. Index is calculated and scenarios are numbered as described for figure 8.

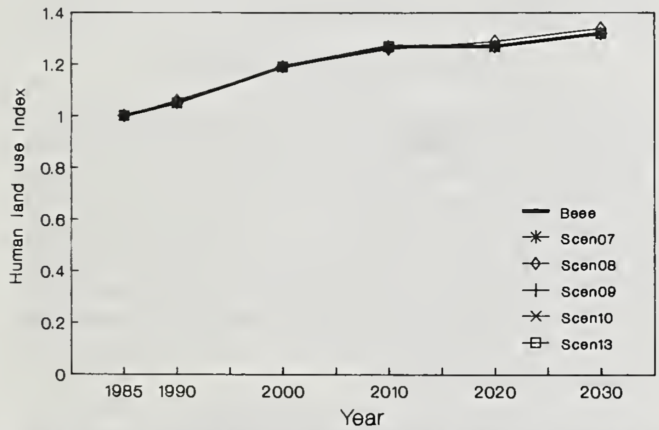


**Figure 10.**—Comparison of human land use among baseline and alternate scenarios for Southeastern coldwater watersheds. Index is calculated and scenarios are numbered as described for figure 8.

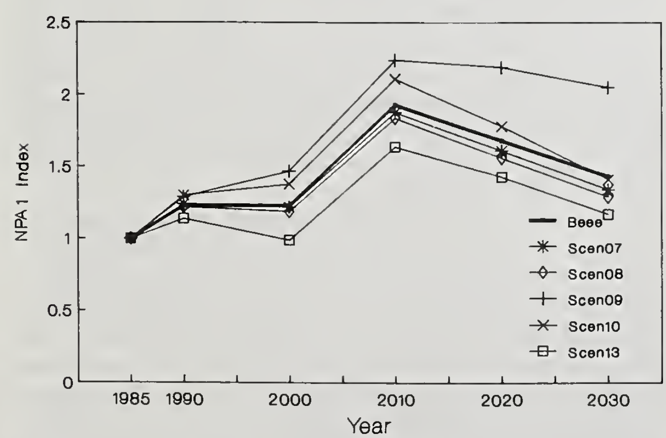


**Figure 11.**—Comparison of young natural pine (0-20 years) among baseline and alternate scenarios for Southeastern coldwater watersheds. Index is calculated and scenarios are numbered as described for figure 8.

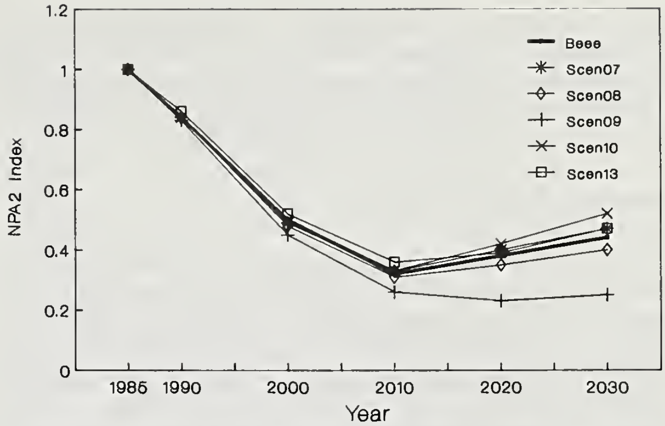


**Figure 12.**—Comparison of middle-age natural pine (21-50 years) among baseline and alternate scenarios for Southeastern coldwater watersheds. Index is calculated and scenarios are numbered as described for figure 8.

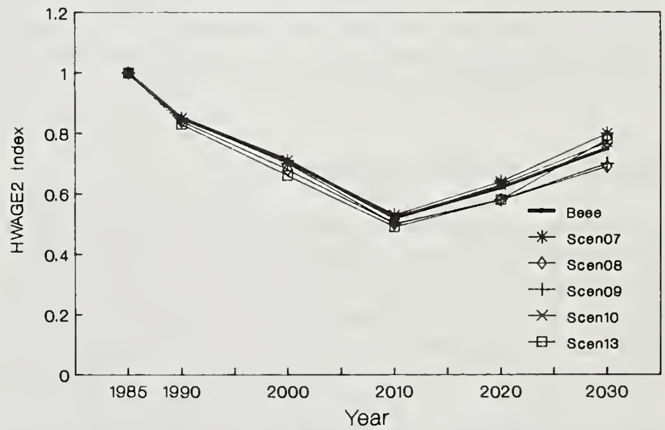


**Figure 13.**—Comparison of middle-age hardwoods (21-50 years) among baseline and alternate scenarios for Southeastern coldwater watersheds. Index is calculated and scenarios are numbered as described for figure 8.

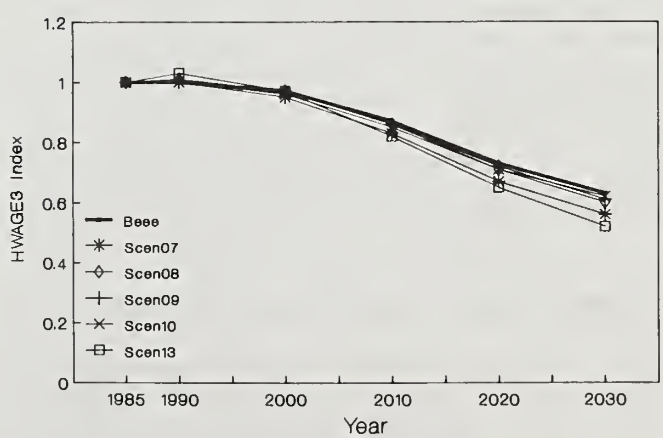


**Figure 14.**—Comparison of old-age hardwoods (over 50 years) among baseline and alternate scenarios for Southeastern coldwater watersheds. Index is calculated and scenarios are numbered as described for figure 8.

land can only be surmised. The watersheds that deviate from baseline behavior are concentrated in northern Virginia, mainly in the Shenandoah Valley, where cropland acreages and the associated increases may occur below trout streams in the watersheds.

### Reduced Timber Growth

Under the decreased timber growth scenario, acres of natural pine in the youngest age class are higher (fig. 11) and acres of natural pines in the 20–50 year age class are lower than in the baseline (fig. 12), especially after 2000. These two forest age class effects tend to cancel in the trout analysis, and the net result is to project trout densities near the baseline densities. The hardwood age class acreages are slightly below baseline (figs. 13–14). Compared to the baseline, the decline of trout density is slightly slower through 2010 and faster after 2010 (fig. 8, table 4). Trout density projected under this scenario is not different from trout density under the baseline projection because the old-age hardwood acreage decrease and human land use acreage increase are not moderated under this scenario, and trout habitat is degraded as in the baseline projection.

### Reduced National Forest Harvest

Under decreased National Forest (NF) harvest, the changes are largely confined to acres of natural pine age classes (figs. 11–12). Even though a large part of the coldwater area is in NF ownership, hardwood types dominate, and natural pine acres are a relatively minor component of forestland. Thus, the impact of reduced NF harvest on trout is minimal. The proportion of land in the hardwood age classes (figs. 13–14) is again very similar to the baseline case. There are some increases in the acreage of natural pine age classes (figs. 11–12), but these differences are both small and transient (as those stands age). The trout analysis is relatively insensitive to natural pine age class acreage shifts; thus, trout density response is similar to the baseline (fig. 8). In 2020 and 2030, trout density drops slightly below baseline, probably due to the increase of middle-age natural pine (fig. 12). The decline of old-age hardwood acreage is as large as the decline projected under the baseline, and acres of human land uses are not modified under this scenario. Degradation of trout habitat associated with these two changes is not modified by the scenario, and trout density declines as in the baseline projection.

### Economic Opportunities on Private Timberland

The limited set of economic opportunities, over and above those in the baseline, result in small differences in land use acreages (figs. 9–10), and some differences in forest type age classes. The largest difference is decreased acres of young natural pine (fig. 11). Middle-age natural pine acres are only slightly above the baseline throughout the projection period (fig. 12). Middle-age hardwood acres are below the baseline from 1990 through 2020 (fig. 13). Old-age hardwood acres decrease more than the baseline (fig. 14); by 2030, the difference appears large, but that difference is small compared to the magnitude of change between 1985 and 2030. The result of the changes to the land base under this scenario is a more rapid decline of trout density between 1990 and 2010 and leveling off after 2010 slightly below the baseline projection (fig. 8). Just as in the baseline projection, trout density declines because old-age hardwood acres decline and human land use acres increase. The assumption of increased economic opportunities under this scenario results in a slightly more rapid degradation of trout habitat than under the baseline projection, and trout density declines more rapidly. After 2010, acres of old-age hardwoods have decreased and acres of human land use have increased to a point where trout density is no longer sensitive to differences in the land base generated by the increased economic opportunities.

## MANAGEMENT AND RESEARCH IMPLICATIONS

### Management Implications

The analysis of present trout density and the land base established the relationship between trout and their watershed habitat on a regional scale. The trout model operated at the level of watersheds and incorporated habitat modifications beyond the immediate stream environment (i.e., forest cover changes in the context of major land use changes). Regional model results indicated that watershed land use management is an important consideration for planning and managing the Southeastern trout fishery.

Alternative scenarios were designed to evaluate impacts of economically important alternatives on supply and inventory volume of timber, especially of softwoods; therefore, land base differences among scenarios were not dramatic for coldwater watersheds. With one exception, the alternative management scenarios tested did not mitigate the decline of trout density observed under the baseline scenario. The model was more sensitive to major land use changes and to harvest of mature hardwood acres than to the details of timber management within the watershed. Management decisions that change harvest of old-age hardwood acres or conversion of forest to human and cropland uses are more likely to be significant to regional trout density than the management alternatives examined here.

Present stream management, including that associated with timber harvest (e.g., leaving riparian buffer strips), was implicit in the model and did not offset effects of land use changes and removal of old-age hardwoods. More intense stream level management, including additional stream habitat improvement, increased trout populations through stocking programs, or trout harvest limitations, may be required to moderate the effect of projected watershed land use and timber harvest. However, this analysis does not identify which, if any, of these management opportunities may successfully mitigate the decline.

The analysis points to the need for management to mitigate the projected decline, particularly in the face of continued increases in numbers of users. If the number of users continues to increase as in the past, will the additional Dingell-Johnson funds generated by expenditures be sufficient to cover increasingly intensive trout management? On the other hand, decreased quality of fishing experience may result in decreased numbers of users, expenditures, and available funds.

The regional trout model presented here provides limited ability to address site-specific management questions. We can say that region-wide harvest of old-age hardwoods results in regional declines of trout density, but we cannot predict what will happen to trout in a particular watershed with this model. Watershed level research would address questions of importance to management of individual watersheds. Although stream habitat is implicit in the relationship between trout density and old-age hardwoods that provide favorable stream conditions for trout, effects of enhanced stream management, such as riparian zone management, cannot be evaluated by this analysis. Finally, the model cannot evaluate the relative effectiveness of watershed management over stream management. Nevertheless, this regional analysis does provide a unique perspective for trout management. The analysis demonstrated that regional landscape patterns, particularly the acreages of old-age hardwoods and human land use, are important to the abundance of trout in the region. Although local stream management is not capable of addressing regional patterns, managing hardwood forests on a regional scale and planning the growth of human related land use may prove successful for maintaining the trout resource.

### Research Opportunities

The objective of the fish analysis was to provide results from which planners and policy makers could assess the possible impacts resulting from changes in land use and timber management activities. In the context of the multiresource framework, this analysis represents an initial effort to quantitatively incorporate other resource considerations into the traditional single resource analysis for a large region. Now that the framework has been specified and applied, we can recommend future research that will permit explicit incorporation of the assumptions made in this analysis. Future research can include more detailed representations of the complex relationships that exist between fish and the land and water resources that affect fish.

Many of the ecological assumptions described above provide opportunities for future research. Trout stocking is significant in the region, and future regional analysis should explicitly incorporate stocking; comparisons of wild trout fisheries with stocked fisheries would be possible with this enhancement to regional analysis. Significant external factors and those implicit in land use and forest cover acreages should be incorporated explicitly in future regional models, as should details of forest and stream management, including riparian buffer strips. More detailed descriptions of the land base within watersheds and of the projected changes would improve the regional model by eliminating the need for assumptions about a homogeneous land base within watersheds and allocation of projected changes. Finally, redefinition of watersheds to create a random and representative sample set of watersheds would eliminate assumptions about runoff and watershed selection.

The regional scale of the trout model presents both opportunities and challenges for future research. The relationships between trout and the watershed habitat established statistically by the model should be verified experimentally for the region and for watersheds. The relative importance of watershed habitat compared to stream habitat should also be addressed with future research.

All models require verification and validation, and this one has not been completely tested. Validation, where model output is compared to independent data, is particularly difficult when predictions are made into the future. Backcasting to earlier time periods is possible, but requires that all three kinds of data—trout abundance, water yield, and land use and forest cover—be available for the same time period. The regional scale of this model presents special problems for validation. An adequate validation requires that comparable data be available for a large portion of the region, not just for a single watershed. Regional trout abundance data are not available for an earlier time. Given these constraints, we are presently limited to internal validation with the jackknife method (Lachenbruch 1975), a verification of the model using the single combined database used to build the model presented here. This research is in progress and will be reported later.

The regional analysis should also be extended to other fish resources, such as warmwater fish, which are a more diverse group and are less specific in their habitat requirements. Warmwater species are expected to present a greater challenge to the researcher. Availability of fish data will limit the opportunities to produce additional regional fish production models.

We can suggest changes for timber growth and yield models that would promote multiple resource analyses. Models that incorporate information about riparian zones associated with forest types would make timber resource projections more responsive to fish habitat management practices. Assumptions of timber growth and yield models should incorporate timber management restrictions imposed by the need to manage fish habitat. Economic supply and demand assumptions should consider the value of other resources like trout. In the future, as income from leasing of fishing rights increases, timber model assumptions about forest owner behavior should be modified.

## CONCLUSIONS

Since stocking programs were initiated that introduced nonnative rainbow and brown trout to the Southeast in

the early 20th century, the range of native brook trout has shrunk. Presently, limited wild brook trout populations persist, primarily in headwater streams. Some wild rainbow trout populations are also found. Populations of all three species are maintained by active stocking programs of both the state and federal hatcheries.

Quadratic discriminant function analysis established relationships between present trout density in trout streams and the watershed land base and runoff. Projected trout density is a function of both land in forest type age classes and land devoted to the major nonforest cropland and human land use. Thus, changes in acres of forestland are considered in combination with changes in acres of nonforest land uses to predict future trout densities. The trout analysis tends to be more sensitive to changes that involve shifts of forestland acres, particularly old hardwoods, into other land uses, especially to human land use.

Although the decline of hardwood acres over the baseline projection period is small, the age structure will change dramatically, resulting in a large decline in old-age hardwood acres in coldwater areas where hardwoods dominate the landscape. Regenerated hardwood stands begin to show up in the middle-age class by 2020; however, none reach old-age status by the end of the projection period in 2030. Trout density declines over time because high trout densities are associated with high acreages of old-age hardwoods. Human land use increases over the projection period contribute to the degradation of trout habitat and trout density.

In general, trout density responses are similar under all scenarios. Differences among the scenarios in acres of cropland, human land use, natural pine and hardwood age classes are small when compared with the change in acres over time. Runoff varies imperceptibly among the scenarios. Most of the scenarios target management related to pine type areas, specifically the dynamics between natural and planted pine types. Those differences represent relatively small acreage shifts for the coldwater areas of Virginia, North Carolina, South Carolina, and Georgia because natural pine is not common and planted pine is very rare. In the analysis, trout density appears to be relatively insensitive to changes in natural pine acreages. Therefore, interpretation of the results must recognize that the scenarios do not necessarily produce changes in acreage of the hardwood forest cover types that are important for high trout density and that dominate the landscape in the coldwater area. Only the Reduced Timberland Area scenario projects a change in land use acres that differs from the baseline, and only in that scenario does trout density respond differently from the baseline.

In the context of continuing increases in fishing, the projected decline of trout production suggests that additional management for trout may be necessary. Management may be focused at regional, watershed, or stream levels. Specific management actions could address either enhanced production through timber management, habitat improvement, or increased stocking, or may require restrictions on trout harvest.

The regional analysis method presented here, imbedded in a multiple resource modeling framework, successfully captured relationships between trout and their watershed habitat. Although numerous assumptions were required, the feasibility of a regional approach to trout habitat relationships was demonstrated. The regional watershed approach allowed us to present future trout production estimates and to evaluate several timber management alternatives. Future timber growth and multiple resource models can explicitly incorporate fish habitat management to achieve more complete analysis of multiple resource questions.

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## APPENDIX: DESCRIPTION OF ALTERNATIVE SCENARIOS

1. **Wharton growth assumptions with cycles**.—The future as described by the basic assumptions and other specified and implied assumptions,[10] modified by substituting the assumptions on population, gross national product, per-capita disposable income, housing and other demand determinants, including economic cycles, contained in "Long-term Alternative Scenarios and 20-year Extension," Wharton Econometric Forecasting Associates, Vol. 3., No. 1, February 1985, for those contained in this study through 2005. For years after 2005, the assumptions used in this report were adjusted to be consistent with the Wharton 20-year trends and levels.

2. **Improved processing efficiency**.—The future as described by the basic assumptions and other specified and implied assumptions,[10] modified by increasing lumber and plywood yields 15 percentage points above the 10% increase assumed in the base projections. The increase in yields will be staged in the progression 9%, 7%, 5%, 3% and 1% per decade.

3. **Fifteen percent softwood lumber tariffs**.—The future as described by the basic assumptions and other specified and implied assumptions,[10] modified by the imposition of a 15% ad valorem duty on softwood lumber imports effective in 1986.

4. **High exports of timber products**.—The future as described by the basic assumptions and other specified and implied assumptions,[10] modified by increasing the projected exports of lumber, plywood, and pulpwood (including pulpwood and the pulpwood equivalent of pulp, paper, and board) by 20% in 1990, 40% in 2000, 60% in 2010, 80% in 2020, and 100 percent in 2030.

5. **High imports of timber products**.—The future as described by the basic assumptions and other specified and implied assumptions,[10] modified by increasing the projected imports of plywood, pulpwood (including pulpwood and the pulpwood equivalent of pulp, paper, and board), and hardwood lumber and logs by 20% in 1990, 40% in 2000, 60% in 2010, 80% in 2020, and 100% in 2030.

6. **Reduced U.S./Canadian exchange rate**.—The future as described by the basic assumptions and other specified and implied assumptions,[10] modified by reducing the U.S. exchange rate with Canada—U.S. dollars per Canadian dollar—to 0.80 in 1990, 0.85 in 2000, and 0.90 in 2030. In the basic assumptions, the exchange rate was assumed to be 0.86 in 1990, 0.95 in 2000 and 0.98 in 2030.

7. **Increased stumpage costs**.—The future as described by the basic assumptions and other specified and implied assumptions,[10] modified by increasing stumpage prices above the base projections by 5% by 1990, 10% by 2000, 15% by 2010, and 20% by 2020.

8. **Reduced timberland area**.—The future as described by the basic assumptions and other specified and implied assumptions,[10] modified by reducing the projected area in timberland in the South by 2 million acres in 1990, 5 million acres in 2000, and 11 million acres in 2030.

9. **Reduced timber growth**.—The future as described by the basic assumptions and other specified and implied assumptions,[10] modified by reducing by 25% the net annual growth on pine plantations, natural pine, and mixed pine-hardwood stands shown in the empirical yield tables used in developing the base-level projections.

10. **Reduced National Forest harvest**.—The future as described by the basic and other specified and implied assumptions,[10] modified by reducing timber harvests on the National Forests to 8.1 billion board-feet in 1990 and maintaining this level through 2030.

11. **Natural regeneration on cropland and pastureland**.—The future as described by the basic assumptions and other specified and implied assumptions,[10] modified by assuming that all the cropland and pastureland in the South that would yield higher rates of return in pine plantations would naturally revert to timberland by 2000 (70% natural pine, 30% hardwoods in the Southeast; 40% natural pine, 60% hardwoods in the South Central).

12. **Economic opportunities on cropland and pastureland**.—The future as described by the basic assumptions and other specified and implied assumptions,[10] modified by assuming that all the economic opportunities (those that would yield 4% or more net of inflation or deflation) for establishing pine plantations on marginal cropland and pastureland would be utilized.

13. **Economic opportunities on private timberlands**.—The future as described by the basic assumptions and other specified and implied assumptions,[10] modified by assuming that all the economic opportunities for increasing timber supplies on timberland in private ownerships that yield 4 percent or more net of inflation or deflation would be utilized.

14. **Increased management intensity on forest industry timberlands in the Douglas-fir region**.—The future as described by the basic assumptions and other specified and implied assumptions,[10] modified by assuming that all the economic opportunities to increase timber supplies on forest industry timberlands in the Douglas-fir region would be utilized.

Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

# Rocky Mountain Forest and Range Experiment Station

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Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

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Laramie, Wyoming
Lincoln, Nebraska
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Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526